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955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: July 20, 1971

to: Distribution

B71 07024

from: K. P. Klaasen

subject: Apollo 15 Launch Vehicle Engine-Out Performance Capability -- Case 310

ABSTRACT

The performance capability of the Apollo 15 launch vehicle has been determined at MSFC for both single and dual simultaneous failures of the S-IC and S-II stage engines. The resulting data are presented in the form of bar graphs in Figures 1-4. For a single S-IC engine failure, at least earth parking orbit can be attained except for failures occurring within about 5 seconds of launch. Translunar injection can be reached for any S-II single engine failure. Dual simultaneous engine failures generally cause loss of vehicle control until the later portions of both S-IC and S-II stage flight. Apollo 15 capability is improved over that of Apollo 14 due primarily to a reduction in the translunar injection (TLI) commit criterion. Safe mission aborts can be performed for all engine failures which cause loss of vehicle control with the possible exception of single S-IC engine failures occurring immediately after launch. In these cases safe aborts cannot be assured due to lack of effective abort cues.

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MEMORANDUM FOR FILE

An analysis of Apollo 15 (AS-510) launch vehicle flight including engine-out malfunctions has been completed at MSFC (Reference 1). The analysis was conducted for a J-type lunar landing mission launched on July 26, 1971, at an 80° launch azimuth and employing the first opportunity trans-lunar injection. The performance capability of the launch vehicle for engine-out malfunctions is presented in Figures 1-4. The data are given in the form of bar graphs which indicate the capability of the vehicle to achieve the various performance plateaus of the mission - translunar injection (TLI), earth parking orbit insertion (POI), and 70 nm perigee contingency orbit insertion (COI) - for given engine-out malfunctions. Both single and dual simultaneous engine failures for the S-IC and S-II stages are considered.

In general, Apollo 15 engine-out capability is improved over that of Apollo 14 (Reference 2). The major differences between the Apollo 15 and Apollo 14 vehicles and missions which affect engine-out performance are:

1. Revised TLI commit criterion.
2. 90 nm earth parking orbit.
3. Smaller Flight Performance Reserve (FPR) requirement (2σ vs. 3σ).
4. Lower inflight wind magnitudes for a July launch.
5. Addition of S-IC center-engine-out tilt arrest logic in the flight program.
6. Modified S-IC pitch/yaw control system.

TLI capability is improved primarily because of the revised TLI commit criterion and the new center-engine-out tilt arrest guidance. The TLI commit criterion for Apollo 14 was the capability to achieve a 105,000 nm apogee orbit at S-IVB second burn cutoff (GCS2) thereby providing for a minimum lunar landing mission. The Apollo 15 TLI commit criterion is the capability to achieve a 42,000 nm apogee orbit at GCS2 thereby providing for a lunar orbit mission.* Vehicle dynamics following an engine out are generally reduced for Apollo 15 due to the lower inflight wind magnitudes. Dual engine-out capability is for the most part unchanged from previous vehicles.

Figure 1 shows that the vehicle can reach at least POI with a single S-IC engine failure except for failures occurring shortly after launch. Capability is also shown to be lower for outboard engine failures than for a center engine failure. This lower capability occurs because the center engine is nominally shut down earlier than the outboard engines and an outboard failure then results in two engines being out after the preset center engine cutoff (CECO) time. Figure 2 indicates that TLI can be reached for any single S-II engine failure. Figure 3 shows that S-IC dual simultaneous engine failures result in loss of vehicle control except in the later portions of flight. Figure 4 indicates that loss of control occurs for S-II adjacent outboard engine failures until the later portions of flight. Opposite S-II engines out result in loss of control shortly after S-IC/S-II separation. At least POI capability exists for failure of the center and one control engine. At least COI capability (including use of an SPS burn) exists for early S-II/S-IVB staging after 195 seconds of S-II flight. Early staging will be performed after this time in the event three or more S-II engines fail rather than performing a spacecraft only abort.

The engine-out malfunctions that result in (1) tower or pad collisions, (2) structural failure of the vehicle, or (3) manual or automatic abort cues make up the regions labeled loss of control. In determining the loss of control regions, effects of all malfunctions were evaluated for an otherwise nominally performing vehicle. For malfunctions where winds have a significant effect, the vehicle was flown in the maximum 95 percentile July wind. The gust was phased with the malfunction to establish a worst case. For malfunctions where winds do not

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*For both Apollo 14 and Apollo 15 engine-out analyses, performance capability was established assuming that one-sigma propellant reserves remain at depletion.

have a significant effect, the average 50 percentile July wind was used. Because the loss of control regions were determined subject to these assumptions, they do not indicate that loss of vehicle control will always occur for the specified engine failure. In general, loss of control becomes more probable the earlier the engine failure occurs.

Mission aborts are required for all malfunctions which result in loss of vehicle control. Safe aborts can be performed except in the case of a single S-IC engine failure occurring shortly after launch. No effective abort cues are available for these early failures, and they result in pad fallback, holddown post collision, or tower collision. Any engine out prior to 0.2 seconds results in pad fallback. Any control engine out between 0.2 and 1.3 seconds results in the vehicle colliding with the holddown posts. Tower collision occurs for a tower-side engine out prior to 5.4 seconds. In these cases safe aborts cannot be assured. During S-IC flight, automatic abort is initiated for a dual engine out malfunction. The automatic abort is automatically inhibited just prior to CECO but may be manually inhibited by the crew at any time. The planned time for the crew to inhibit automatic abort is 120 seconds after liftoff for nominal flight because simultaneous engine failures prior to this time can cause pad fallback or failure of the CSM structural interface. The most probable cues for a manual abort due to dual engine out during S-IC flight after 120 seconds and during S-II flight are (1) two engine-out lights and (2) 10°/sec overrate light. The overrate cue occurs because a dual engine out, especially simultaneous failure of adjacent outboard engines, causes a large thrust unbalance and large dynamic transients.

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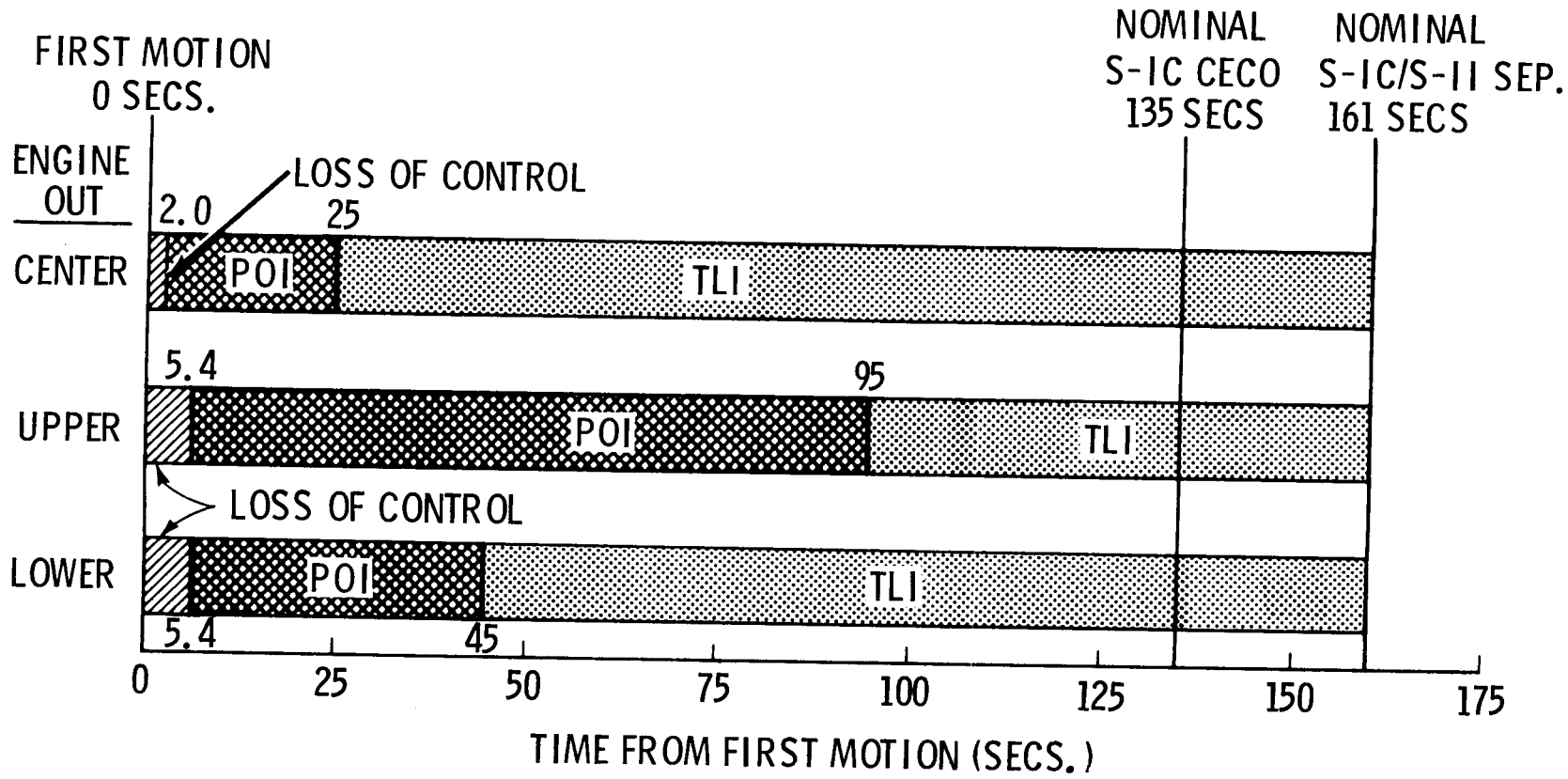
REFERENCES

1. MSFC Memorandum, S&E-AERO-MFT-87-71, "Saturn V AS-510 (Apollo 15) Launch Vehicle Malfunction Flight Analysis," June 28, 1971.

2. Klaasen, K. P., "Apollo 14 Launch Vehicle Engine-Out Performance Capability," Bellcomm Memorandum for File B71 01025, January 21, 1971.

3. Klaasen, K. P., "Saturn V Engine-Out Performance Capability," Bellcomm Memorandum for File B70 07101, July 31, 1970.



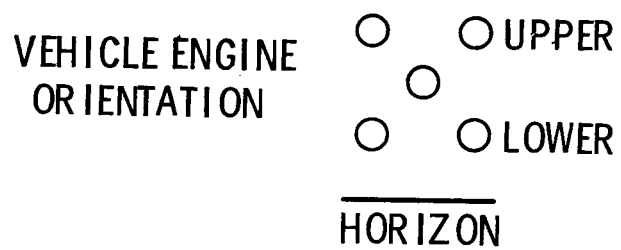


FIGURE 1 - S-IC SINGLE ENGINE OUT CAPABILITY (APOLLO 15)

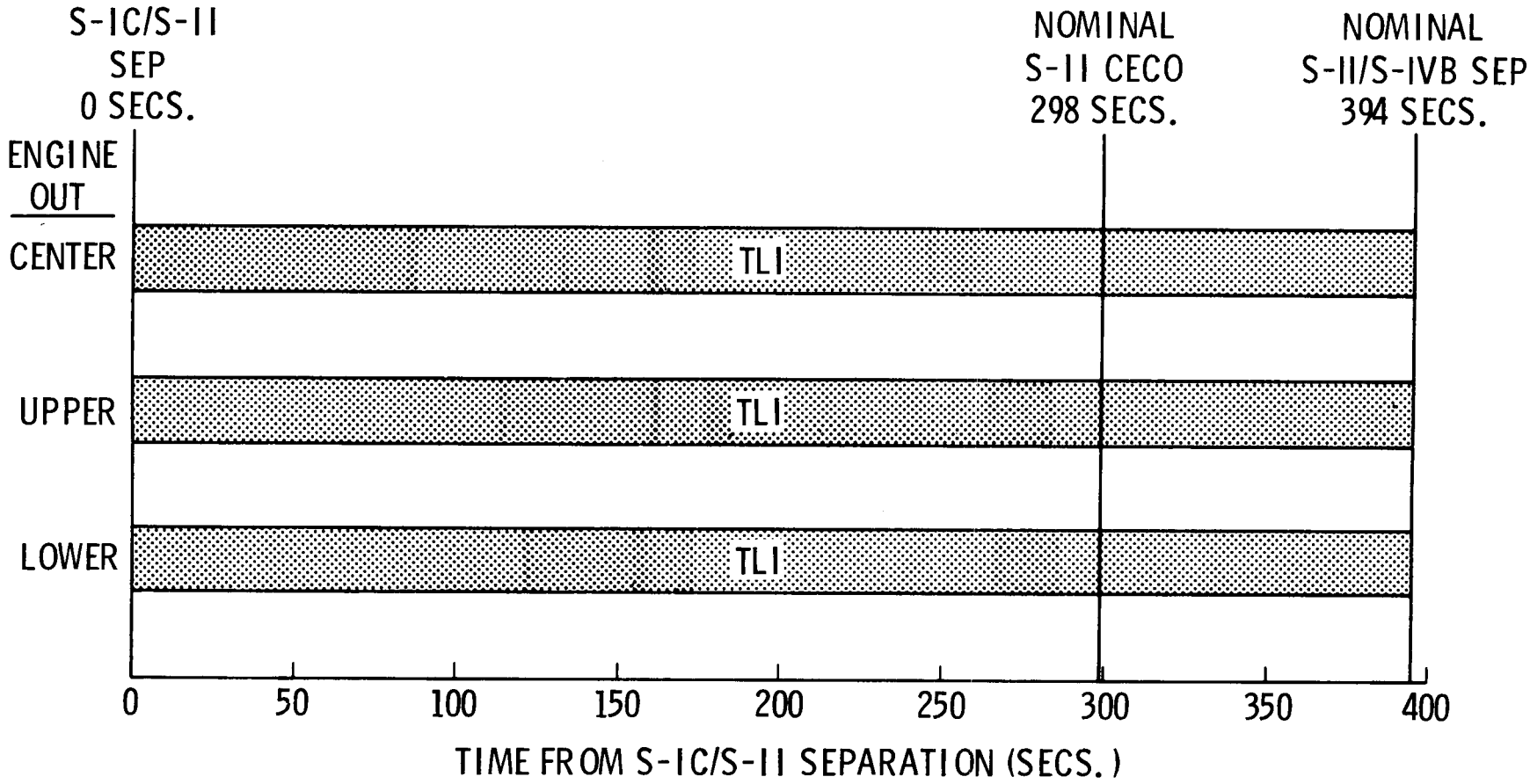


FIGURE 2 - S-II SINGLE ENGINE OUT CAPABILITY (APOLLO 15)

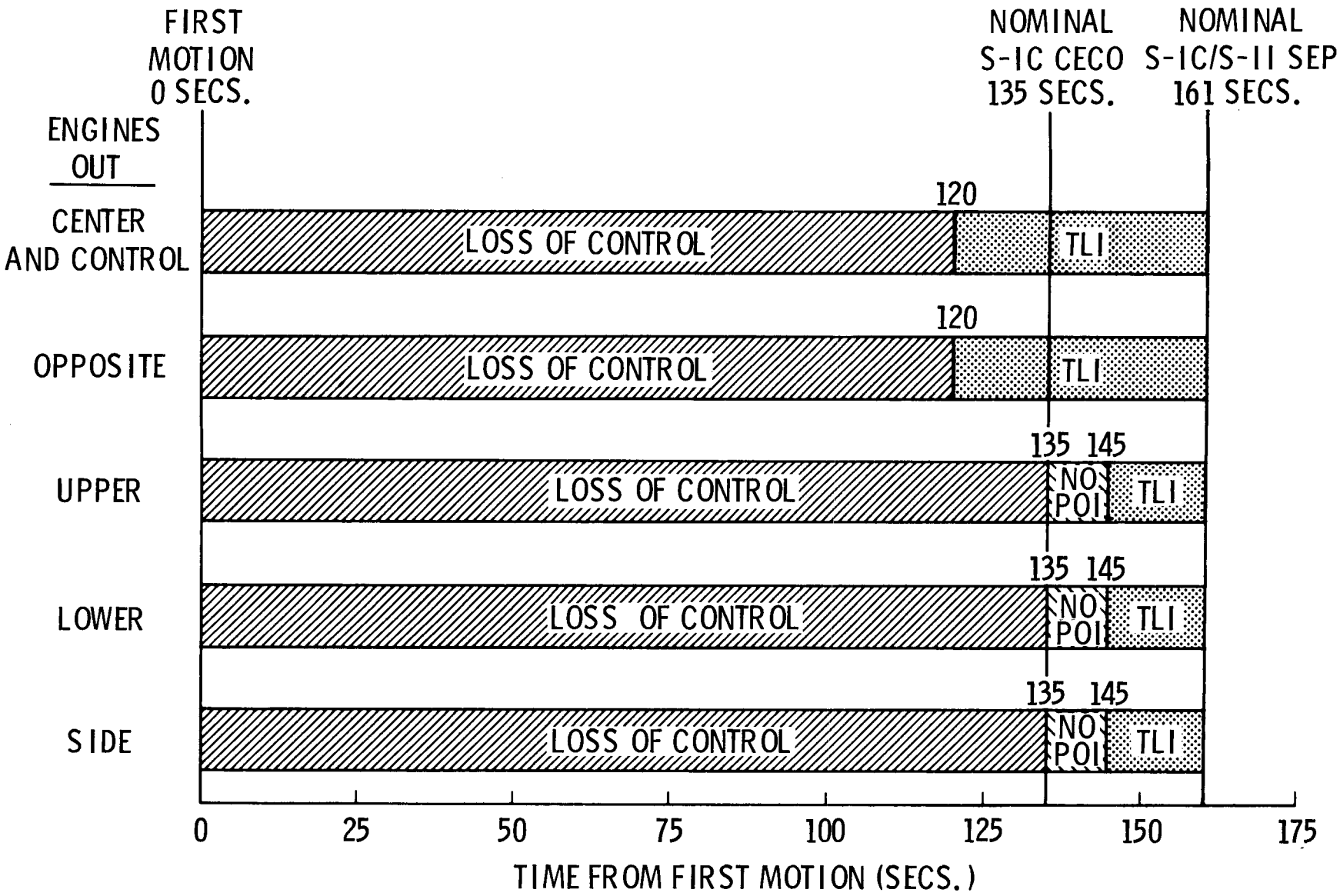


FIGURE 3 - S-IC DUAL SIMULATANEOUS ENGINE OUT CAPABILITY (APOLLO 15)

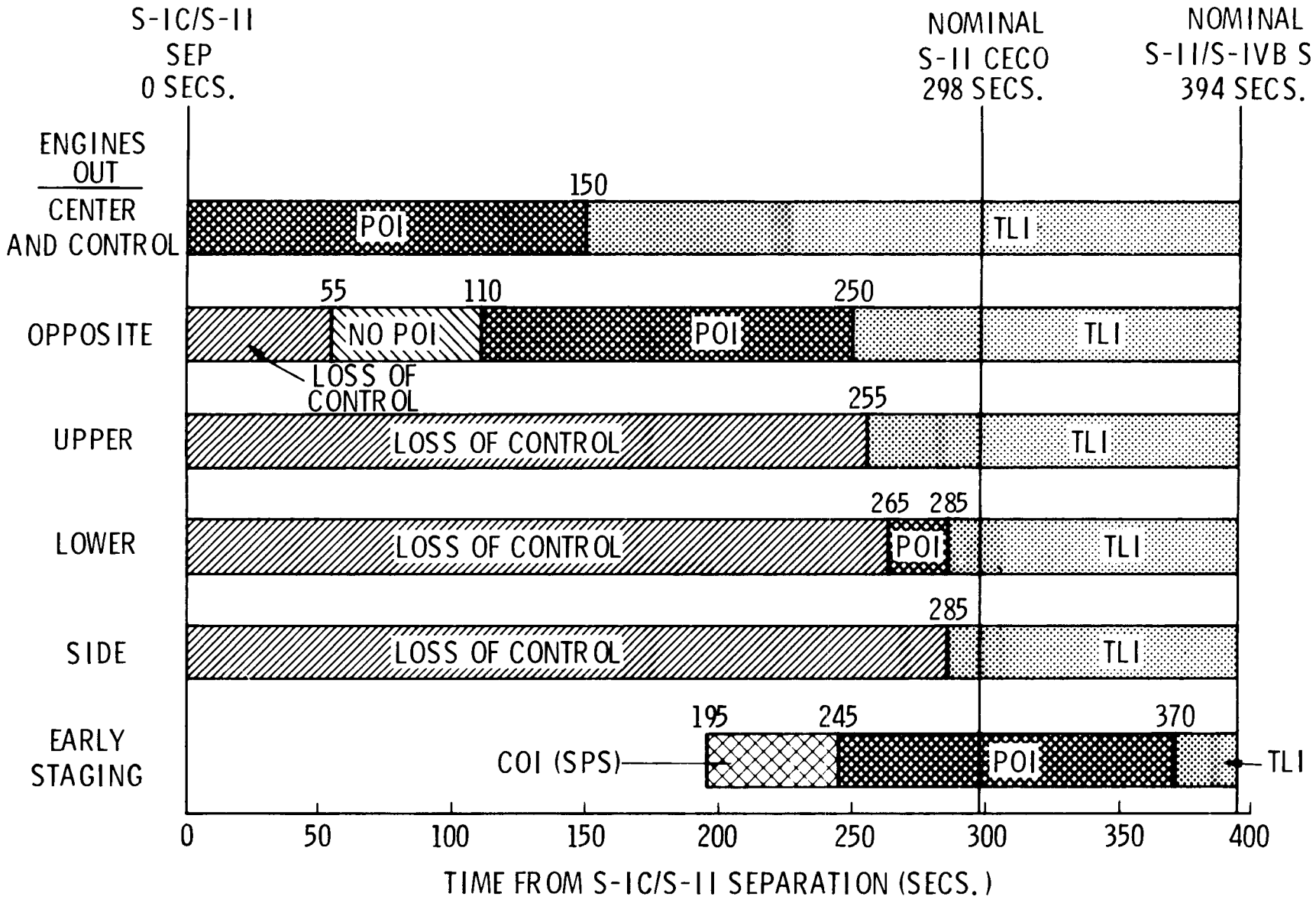


FIGURE 4 - S-II DUAL SIMULTANEOUS ENGINE OUT AND EARLY STAGING CAPABILITY (APOLLO 15)

SUBJECT: Apollo 15 Launch Vehicle Engine-Out Performance Capability - Case 310

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